Table 1

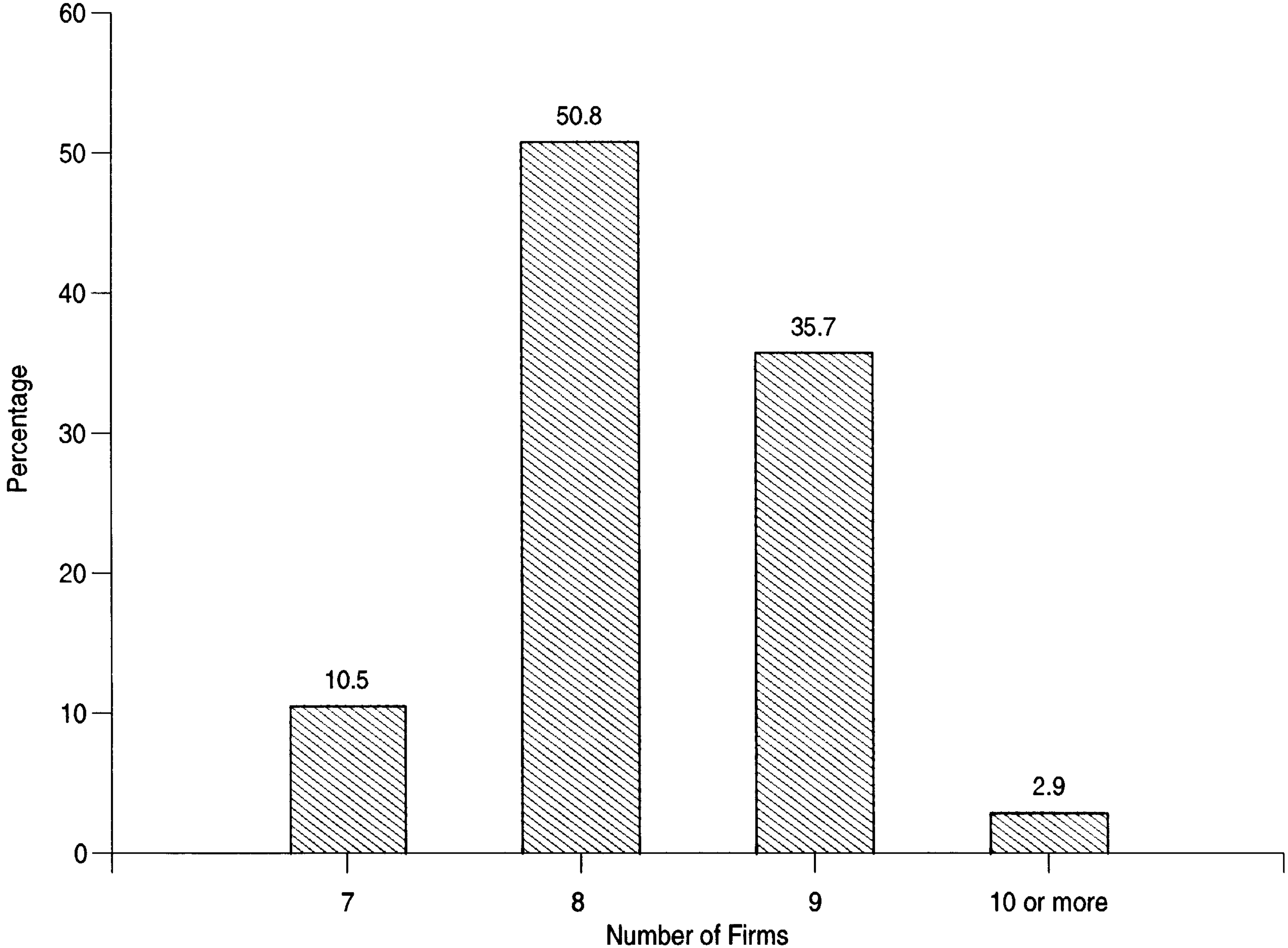
Examples of Firms that Hold Only 10 MHz in a Top 50 MSA

Firm	MSA Name	MSA Rank	Average D/E Winning Dollars/BTA Pop
Alltel	Atlanta, GA	17	10.95
	Kansas City, MO	24	2.75
	Memphis, TN	36	2.50
	Birmingham, AL	41	4.20
AT&T	San Diego, CA	18	3.50
	Milwaukee, WI	21	2.45
	Indianapolis, IN	28	1.35
	Birmingham, AL	41	4.20
	Bridgeport, CT	42	2.25
	Albany, NY	44	2.45
	Honolulu, HI	50	5.95
Omnipoint	Washington, D.C.	8	1.60
	St. Louis, MO	11	0.75
	Baltimore, MD	14	2.25
	Indianapolis, IN	28	1.35
	San Antonio, TX	33	1.85
	Providence, RI	38	2.45
	Birmingham, AL	41	4.20
	Norfolk, VA	43	2.35
	Nashville, TN	46	2.25
Sprint	Houston, TX	10	2.85
	Cleveland, OH	16	3.30
	Atlanta, GA	17	10.95
	Tampa, FL	22	19.25
	Cincinnati, OH	23	4.75
	Memphis, TN	36	2.50
	Dayton, OH	40	1.45
	Norfolk, VA	43	2.35
	Greensboro, NC	47	5.50
	Honolulu, HI	50	5.95
Western Wireless	San Francisco, CA	7	1.90
	St. Louis, MO	11	0.75
	Cleveland, OH	16	3.30
	Seattle, WA	20	2.75
	Milwaukee, WI	21	2.45
	Phoenix, AZ	26	4.40
	San Jose, CA	27	1.90
	San Antonio, TX	33	1.85
	Dayton, OH	40	1.45
	Norfolk, VA	43	2.35

Figure 2

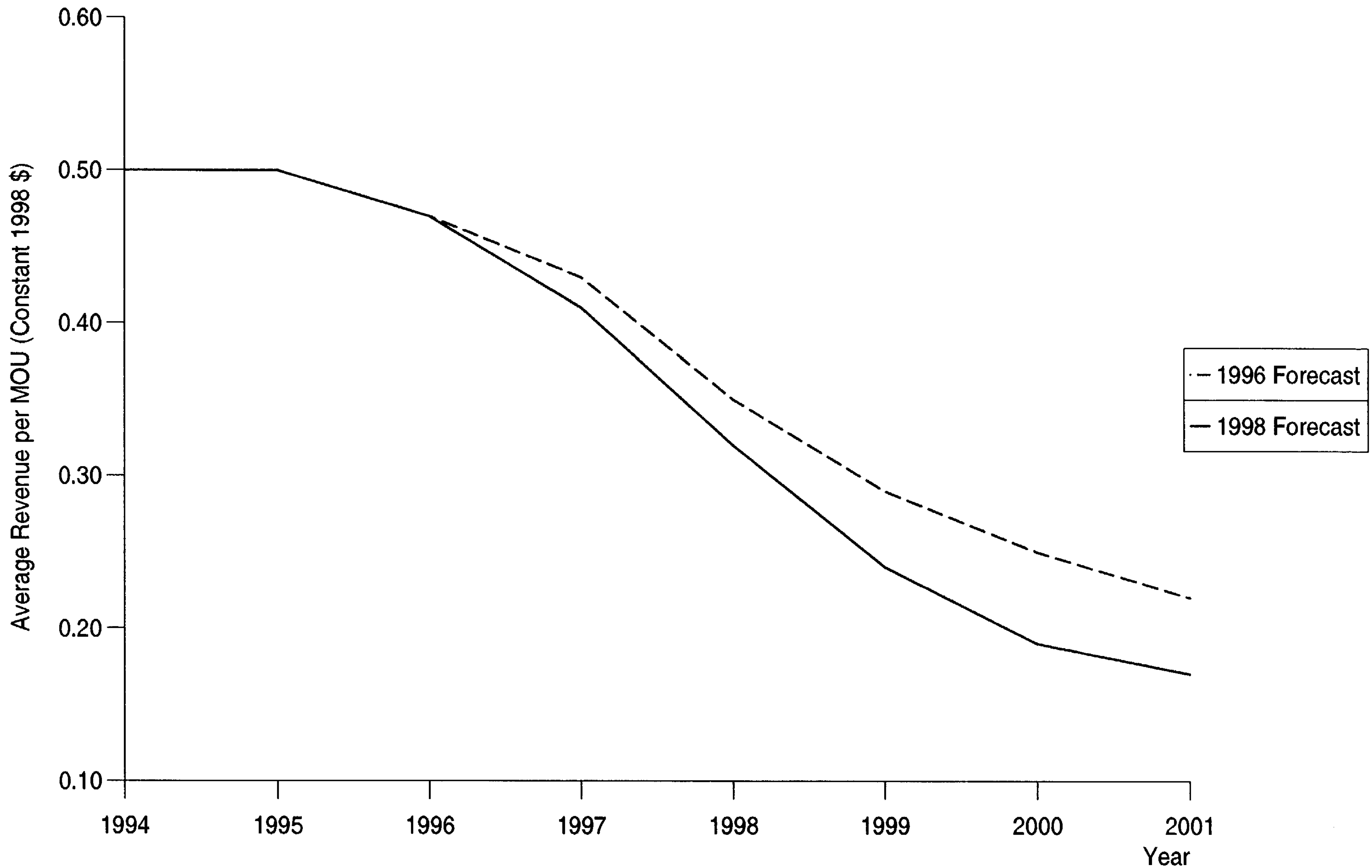
Distribution of Number of Firms That Own Wireless Spectrum in an MSA

All MSAs



Note: Includes cellular providers and holders of PCS and EMSR licenses.

Figure 3
Decline in Forecast Prices



Source: The Wireless Communications Industry, Donaldson, Lufkin & Jenrette, Summer 1996 Ed. at 16 & Spring 1988 Ed. at 20.

Table 2

Summary of Regression Analyses of Cellular Prices
As of March 1998

Logarithm of Price of:	30 MOU	100 MOU	300 MOU	500 MOU	750 MOU	1000 MOU
One or More PCS Operators	-0.067	-0.162	-0.179	-0.182	-0.158	-0.143
	(-1.32)	(-2.89)	(-2.57)	(-2.93)	(-2.22)	(-1.78)
Two or More PCS Operators	0.070	0.102	-0.022	-0.026	-0.054	-0.068
	(1.94)	(2.54)	(-0.43)	(-0.59)	(-1.06)	(-1.18)
Three PCS Operators	-0.008	-0.009	0.055	0.037	0.052	0.092
	(-0.15)	(-0.15)	(0.76)	(0.59)	(0.71)	(1.12)
Adjusted R^2	0.1528	0.1655	0.2007	0.2656	0.2008	0.1875

t statistics reported in parentheses.

Notes: Based on information from Top 100 MSAs.

Regressions also include log (Median Household Income), log (Population Density), log (Travel Time), log (Traffic Density) and dummy variables for the presence of Nextel as explanatory variables.

Table 3

Summary of Regression Analyses of Cellular Prices
As of March 1998

Logarithm of Price of:	30 MOU	100 MOU	300 MOU	500 MOU	750 MOU	1000 MOU
Months Since First PCS Launch	-0.0026 (-1.14)	-0.0086 (-3.51)	-0.0137 (-4.59)	-0.0130 (-4.94)	-0.0122 (-3.90)	-0.0128 (-3.64)
Months Since Second PCS Launch	0.0073 (2.33)	0.0136 (4.06)	0.0065 (1.60)	0.0044 (1.21)	0.0031 (0.72)	0.0029 (0.60)
Months Since Third PCS Launch	0.0054 (0.35)	-0.0133 (-0.81)	-0.0127 (-0.64)	-0.0000 (-0.00)	0.0064 (0.31)	0.0191 (0.81)
Adjusted R^2	0.1629	0.2327	0.3004	0.3624	0.2677	.2550

t statistics reported in parentheses.

Notes: Based on information from Top 100 MSAs.

Regressions also include log (Median Household Income), log (Population Density), log (Travel Time), log (Traffic Density) and dummy variables for the presence of Nextel as explanatory variables.

Appendix Table 1

Prices of Cellular Service in the Top 50 MSAs
1996, 1998

MSA	MSA Name	Service	250 MOUs 1996		300 MOUs 1998		Percentage Difference	
			Price	Price Per Minute	Price	Price Per Minute	Price	Price Per Minute
1	NEW YORK, NY	Non-Wireline	142.24	0.57	153.99	0.51	8.26	-9.78
		Wireline	137.49	0.55	99.99	0.33	-27.27	-39.40
2	LOS ANGELES, CA	Non-Wireline	121.19	0.48	59.99	0.20	-50.50	-58.75
		Wireline	121.19	0.48	111.99	0.37	-7.59	-22.99
3	CHICAGO, IL	Non-Wireline	82.50	0.33	54.95	0.18	-33.39	-44.49
		Wireline	86.65	0.35	45.00	0.15	-48.07	-56.72
4	PHILADELPHIA, PA	Non-Wireline	84.99	0.34	93.49	0.31	10.00	-8.33
		Wireline	84.49	0.34	59.99	0.20	-29.00	-40.83
5	DETROIT, MI	Non-Wireline	84.74	0.34	47.99	0.16	-43.37	-52.81
		Wireline	87.20	0.35	93.20	0.31	6.88	-10.93
6	BOSTON, MA	Non-Wireline	87.53	0.35	88.95	0.30	1.62	-15.31
		Wireline	88.24	0.35	62.49	0.21	-29.18	-40.98
7	SAN FRANCISCO, CA	Non-Wireline	119.99	0.48	59.99	0.20	-50.00	-58.34
		Wireline	119.20	0.48	59.50	0.20	-50.08	-58.40
8	WASHINGTON, DC	Non-Wireline	71.00	0.28	70.24	0.23	-1.07	-17.56
		Wireline	77.74	0.31	62.49	0.21	-19.62	-33.01
9	DALLAS, TX	Non-Wireline	57.99	0.23	49.99	0.17	-13.80	-28.16
		Wireline	66.25	0.27	65.00	0.22	-1.89	-18.24
10	HOUSTON, TX	Non-Wireline	95.47	0.38	45.00	0.15	-52.86	-60.72
		Wireline	99.20	0.40	50.00	0.17	-49.60	-58.00
11	ST LOUIS, MO	Non-Wireline	83.10	0.33	76.45	0.25	-8.00	-23.34
		Wireline	84.08	0.34	52.95	0.18	-37.02	-47.52

Appendix Table 1

Prices of Cellular Service in the Top 50 MSAs
1996, 1998

MSA	MSA Name	Service	250 MOUs 1996		300 MOUs 1998		Percentage Difference	
			Price	Price Per Minute	Price	Price Per Minute	Price	Price Per Minute
12	MIAMI, FL	Non-Wireline	83.35	0.33	49.99	0.17	-40.02	-50.02
		Wireline	99.95	0.40	55.00	0.18	-44.97	-54.14
13	PITTSBURGH, PA	Non-Wireline	89.99	0.36	52.99	0.18	-41.12	-50.93
		Wireline	87.45	0.35	64.99	0.22	-25.68	-38.07
14	BALTIMORE, MD	Non-Wireline	71.00	0.28	70.24	0.23	-1.07	-17.56
		Wireline	77.74	0.31	62.49	0.21	-19.62	-33.01
15	MINNEAPOLIS, MN	Non-Wireline	92.99	0.37	50.00	0.17	-46.23	-55.19
		Wireline	87.95	0.35	99.95	0.33	13.64	-5.30
16	CLEVELAND, OH	Non-Wireline	108.74	0.43	97.99	0.33	-9.89	-24.90
		Wireline	113.25	0.45	87.50	0.29	-22.74	-35.61
17	ATLANTA, GA	Non-Wireline	91.95	0.37	75.00	0.25	-18.43	-32.03
		Wireline	97.33	0.39	45.00	0.15	-53.77	-61.47
18	SAN DIEGO, CA	Non-Wireline	99.75	0.40	80.00	0.27	-19.80	-33.17
		Wireline	103.75	0.42	65.00	0.22	-37.35	-47.79
19	DENVER, CO	Non-Wireline	65.99	0.26	49.99	0.17	-24.25	-36.87
		Wireline	98.58	0.39	50.00	0.17	-49.28	-57.73
20	SEATTLE, WA	Non-Wireline	86.59	0.35	65.99	0.22	-23.79	-36.49
		Wireline	68.95	0.28	95.40	0.32	38.36	15.30
21	MILWAUKEE, WI	Non-Wireline	114.45	0.46	48.35	0.16	-57.75	-64.80
		Wireline	86.65	0.35	56.40	0.19	-34.91	-45.76
22	TAMPA, FL	Non-Wireline	83.35	0.33	49.99	0.17	-40.02	-50.02
		Wireline	108.45	0.43	50.00	0.17	-53.90	-61.58

Appendix Table 1

Prices of Cellular Service in the Top 50 MSAs 1996, 1998

			250 MOUs 1996		300 MOUs 1998		Percentage Difference	
MSA	MSA Name	Service	Price	Price Per Minute	Price	Price Per Minute	Price	Price Per Minute
23	CINCINNATI, OH	Non-Wireline	97.42	0.39	77.99	0.26	-19.94	-33.29
		Wireline	88.40	0.35	72.70	0.24	-17.76	-31.47
24	KANSAS CITY, MO	Non-Wireline	92.25	0.37	58.70	0.20	-36.37	-46.97
		Wireline	89.08	0.36	72.95	0.24	-18.11	-31.76
25	BUFFALO, NY	Non-Wireline	71.13	0.28	66.15	0.22	-7.00	-22.50
		Wireline	74.97	0.30	59.95	0.20	-20.03	-33.36
26	PHOENIX, AZ	Non-Wireline	94.37	0.38	39.99	0.13	-57.62	-64.69
		Wireline	97.25	0.39	49.95	0.17	-48.64	-57.20
27	SAN JOSE, CA	Non-Wireline	119.99	0.48	59.99	0.20	-50.00	-58.34
		Wireline	119.20	0.48	59.50	0.20	-50.08	-58.40
28	INDIANAPOLIS, IN	Non-Wireline	84.25	0.34	79.95	0.27	-5.10	-20.92
		Wireline	76.75	0.31	87.50	0.29	14.01	-4.99
29	NEW ORLEANS, LA	Non-Wireline	99.00	0.40	67.50	0.23	-31.82	-43.18
		Wireline	99.00	0.40	119.35	0.40	20.56	0.46
30	PORTLAND, OR	Non-Wireline	66.60	0.27	49.99	0.17	-24.94	-37.45
		Wireline	82.95	0.33	76.20	0.25	-8.14	-23.45
31	COLUMBUS, OH	Non-Wireline	97.42	0.39	77.99	0.26	-19.94	-33.29
		Wireline	88.40	0.35	72.70	0.24	-17.76	-31.47
32	HARTFORD, CT	Non-Wireline	115.95	0.46	62.49	0.21	-46.11	-55.09
		Wireline	113.58	0.45	88.75	0.30	-21.86	-34.88
33	SAN ANTONIO, TX	Non-Wireline	57.99	0.23	49.99	0.17	-13.80	-28.16
		Wireline	74.45	0.30	86.70	0.29	16.45	-2.96

Appendix Table 1

Prices of Cellular Service in the Top 50 MSAs 1996, 1998

MSA	MSA Name	Service	250 MOUs 1996 Price	250 MOUs 1996 Price Per Minute	300 MOUs 1998 Price	300 MOUs 1998 Price Per Minute	Percentage Difference Price	Percentage Difference Price Per Minute
34	ROCHESTER, NY	Non-Wireline	78.75	0.32	62.25	0.21	-20.95	-34.13
		Wireline	74.97	0.30	59.95	0.20	-20.03	-33.36
35	SACRAMENTO, CA	Non-Wireline	77.49	0.31	55.59	0.19	-28.26	-40.22
		Wireline	75.99	0.30	49.99	0.17	-34.22	-45.18
36	MEMPHIS, TN	Non-Wireline	99.95	0.40	47.50	0.16	-52.48	-60.40
		Wireline	87.95	0.35	45.00	0.15	-48.83	-57.36
37	LOUISVILLE, KY	Non-Wireline	87.45	0.35	88.95	0.30	1.72	-15.24
		Wireline	94.75	0.38	55.00	0.18	-41.95	-51.63
38	PROVIDENCE, RI	Non-Wireline	84.99	0.34	83.49	0.28	-1.76	-18.14
		Wireline	88.24	0.35	104.49	0.35	18.42	-1.32
39	SALT LAKE CITY, UT	Non-Wireline	65.99	0.26	49.99	0.17	-24.25	-36.87
		Wireline	95.20	0.38	107.45	0.36	12.87	-5.94
40	DAYTON, OH	Non-Wireline	97.42	0.39	77.99	0.26	-19.94	-33.29
		Wireline	88.40	0.35	72.70	0.24	-17.76	-31.47
41	BIRMINGHAM, AL	Non-Wireline	85.95	0.34	44.00	0.15	-48.81	-57.34
		Wireline	90.15	0.36	81.00	0.27	-10.15	-25.12
42	BRIDGEPORT, CT	Non-Wireline	115.95	0.46	100.24	0.33	-13.55	-27.96
		Wireline	113.58	0.45	88.75	0.30	-21.86	-34.88
43	NORFOLK, VA	Non-Wireline	78.15	0.31	73.75	0.25	-5.63	-21.36
		Wireline	79.95	0.32	87.50	0.29	9.44	-8.80
44	ALBANY, NY	Non-Wireline	71.13	0.28	84.25	0.28	18.45	-1.30
		Wireline	64.99	0.26	81.49	0.27	25.39	4.49

CMRS Capacity: Expanded Use and Expanded Spectrum

Declaration of Dr. Charles L. Jackson

Qualifications

1. My name is Charles L. Jackson. I am an independent consultant specializing in telecommunications. I received my undergraduate degree in applied mathematics, with honors, from Harvard College in 1966. I received an M.S. in electrical engineering from the Massachusetts Institute of Technology (MIT) in 1974 and a Ph.D. in electrical engineering from MIT in 1977. I have worked for more than twenty years in the electronics and communications industry. I am currently also an adjunct professor of electrical engineering and computer science at George Washington University, where I teach a graduate course in mobile communications. A copy of my full biography is attached as an appendix and is incorporated herein by reference.

Summary

2. Below, I give an overview of current data networking capabilities and projected needs. Second, I review the growth of the Internet and evidence for the general concept of wireless networking. Third, I describe research on wireless networking supported by DARPA and the European Union, projections for public safety use of wireless data, and projections for nonvoice communications made by the Land Mobile Communications Council and offer conclusions on the future demand for wireless data. Fourth, I combine estimates of such future demand with the capacity of current state-of-the-art mobile communications systems and show that, under reasonable assumptions, the capacity of a firm operating at the spectrum cap would be insufficient to serve a substantial number of wireline customers in urban areas. Fifth, I identify radio spectrum that is technically suitable for CMRS service that the Commission could convert to CMRS use if it were concerned about any restriction of output in the CMRS industry. Finally, I offer two conclusions: (1) new communications applications, primarily wireless interconnection to the Internet, will increase the demand for CMRS services, and (2) consumers would be

better served if the FCC expanded the radio spectrum available for CMRS rather than restricting the operation of CMRS firms through artificial spectrum caps.

Current Capabilities and Projected Needs for Mobile Data Networking

3. The recent growth in data communications and computer networking has surprised many. CMRS suppliers have lagged behind telephone and cable companies in the delivery of data services. The primary means of data communications in first-generation cellular systems was the connection of an analog modem to a cellular phone. This approach was severely limited by the technical characteristics of the cellular connection and the cost of cellular service. Second generation designs, such as GSM or CDMA (IS-95), include a limited data communications capability that is a native part of the system architecture. Here in the United States, several cellular carriers have also deployed a data networking capability called *cellular digital packet data* (CDPD), which operates on cellular channels but uses a technology distinct from that used for the cellular voice service. The limited current capabilities for wireless data do not represent the likely future. Rather, I expect that we will see an explosion in the use of wireless data over the next decade.

4. Noted computer scientist and Internet pioneer Leonard Kleinrock coined the term *nomadicity* to refer to use of networked computers by individuals roaming from location to location. He described described some of the benefits and technical challenges:

> There are a number of compelling reasons why nomadicity is of interest. For example, nomadicity is clearly a newly emerging technology that users are already surrounded with. Indeed, this author judges it to be a paradigm shift in the way computing will be done in the future. Information technology trends are moving in this direction. Nomadic computing and communications is a multidisciplinary and multi-institutional effort. It has a huge potential for improved capability and convenience for the user. . . . The needs are real. The issues are fascinating. It makes all the problems harder. The payoffs can be huge.[1]

[1] Leonard Kleinrock, "Nomadicity, Anytime, Anywhere in a Disconnected World" (Technology Transfer Institute, undated).

5. Similarly, University of Pennsylvania professor Jonathan Smith described his views of future mobile data communications:

> Low-cost, minimal-sized, long-lived, and low-powered microprocessors have enabled new thin-client forms of untethered distributed computing, exemplified by 3Com's PalmPilot machine. While they are "thin" (containing no keyboard, disk, or large display), it is attractive to make these devices full-fledged network participants."[2]

6. These academic authors are at the forefront of computer networking research. Their work permits them to identify future capabilities and needs. These two quotations illustrate a clear vision of a future with pervasive mobile and untethered computing use and network access.

Internet Connectivity

7. The recent growth of the Internet has surprised many.[3] In this section, I examine the impact of Internet growth on the demand for wireless service. The Internet has grown, and continues to grow, at enormous rates.[4] Today, there are roughly 40 million computers (hosts) connected to the Internet. In contrast, five years ago, January 1994,

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2 Jonathan M. Smith, "Selected Challenges in Computer Networking," *IEEE Computer*, 32, no. 1 (January 1999) 40–42.

3 While the Internet has grown to prominence recently, it reflects decades of research and evolution. A good popular history of the Internet is given in *Where Wizards Stay Up Late: The Origins of the Internet* by Katie Hafner and Matthew Lyon (Simon & Schuster, 1996). A shorter history, written by several of the key participants in the development of the Internet, is *A Brief History of the Internet, Version 3.1* by Barry M. Leiner, Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Roberts, and Stephen Wolff (available from the Internet Society at www.isoc.org, 1998). A history of the Internet is also provided in "Digital Tornado: The Internet and Telecommunications Policy" by Kevin Werbach, (FCC-OPP Working Paper 29, 1997).

4 See Appendix 2, "Building Out the Internet," in US Department of Commerce, *Emerging Digital Economy*, with Appendices (NTIS order number PB98-137029, April 1998).

there were slightly more than 3 million computers connected to the Internet. Traffic carried on the Internet doubles every hundred days.

8. A recent Department of Commerce report credited information technology and the Internet with spurring the growth of productivity in the economy:

> Businesses in virtually every sector of the economy are beginning to use the Internet to cut the cost of purchasing, manage supplier relationships, streamline logistics and inventory, plan production, and reach new and existing customers more effectively. Cost savings, increased consumer choice and improved consumer convenience are driving growth in the sale of physical goods and in the digital delivery of goods and services via the Internet. Because the Internet is new and its uses are developing very rapidly, reliable economy-wide statistics are hard to find. Further research is needed. This report therefore uses industry and company examples to illustrate the rapid pace at which Internet commerce is being deployed and the benefits are being realized.[5]

9. One highly visible aspect of the Internet is the World Wide Web. The Web came into being in the early 1990s based upon work by Tim Berners-Lee at the European Center for Nuclear Research (CERN). The Web allows one to prepare and publish text and graphical documents over the Internet. The technology needed to access the Internet and the Web is widely available. Most computers being installed today come with Internet software and a web browser already installed. As a consequence of the wide availability and ease of use of web browsers, organizations are using them in many ways.

10. Indeed, many believe that the growth of the Web and the Internet and the growth in dial-up usage have been responsible for problems in the existing wire infrastructure.[6]

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[5] Ibid., 2.

[6] See, for example, the discussion in Werbach (op. cit., note 3). The local exchange carriers are reported to have spent many millions expanding central office capacity to support dial-in Internet traffic. Similarly, some cable systems offering cable-modem Internet access to consumers have run into service quality problems as usage has grown.

Naturally enough, there has been intense interest in wireless access to the Internet. Below, I describe some of the early products, trials, and research efforts regarding wireless access to the Internet.

State-of-the-Art Equipment

11. First, consider the current state of the commercial art. Nokia has been selling their Communicator — an advanced GSM telephone, pictured in Figure 1 below, for about a year. The Nokia Communicator provides a digital cellular phone with a data/fax modem, an Internet access terminal, and a personal organizer. It also has an infrared link to support printing. At the heart of the Communicator is an Intel 386 processor with 8 megabytes of memory — a configuration roughly comparable to a desktop computer of seven years ago. The Communicator has a small (640x200 pixel) grey-scale display and a keyboard. It comes with software for email and access to the World Wide Web. But, clearly, the performance of this unit is limited. The display screen is small and in grey-scale. Battery life is short (up to two hours of active time), and communications are relatively slow (9600 bits per second). Nevertheless, many users of the Communicator are quite enthusiastic about this product.

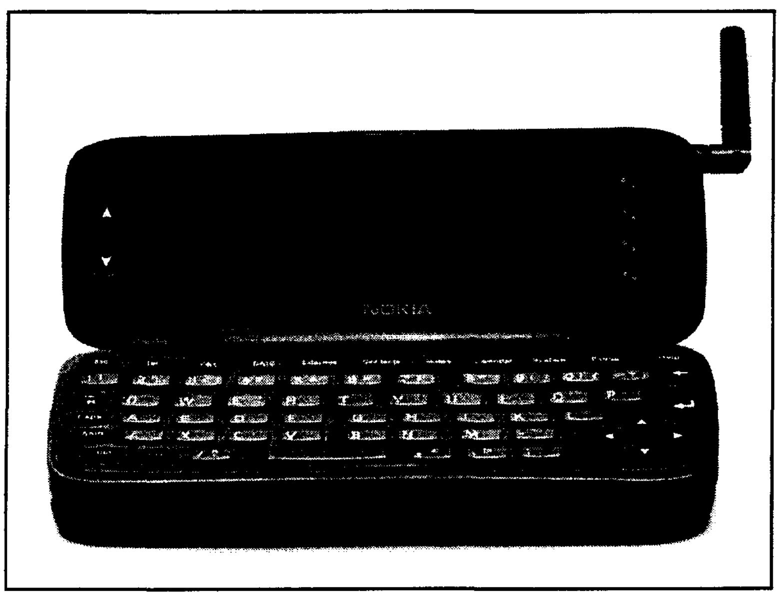

Figure 1. Nokia Communicator.

12. As impressive as the Nokia Communicator is, the access it offers to the Internet is primitive compared with the access people are used to at their desks. Today, there is a substantial research effort aimed at improving wireless access to the Internet. Some of this effort revolves around networking protocols themselves. Examples of the kind of topics being studied include (1) how to organize networks to provide a consistent interface to terminals or users that connect to the network by varying methods over the course of a day or week and (2) how to expand the capacity of wireless links and how to make wireless links more efficient in the support of Internet applications such as email or web browsing.

Wireless Internet Access

13. A quite different approach to data networking is provided by Metricom's Ricochet service.[7] Ricochet operates in the unlicensed 902-928 MHz ISM band using frequency-hopping spread-spectrum modulation under Part 15 of the FCC rules. Ricochet provides an Internet access service. Usually, ISP service is bundled with the bit transport service. The Ricochet service provides always-on Internet connectivity at speeds up to 28 kbps. I have been told by some users of the service that they sometime get communications at higher rates as well. Ricochet provides Internet connectivity roughly the same as what people are accustomed to over dial-up connections. Thus, it is quite acceptable for use with portables. Unfortunately, the geographic availability of Ricochet is quite limited. It is available only in Seattle; San Francisco; the Washington, DC, area; eleven airports; and some corporate campuses. Metricom is testing a new technology that will support communications at 128 kbps. Metricom currently has about 25,000 customers and claims

[7] There are other radio services, such as narrowband PCS, that supply some limited mobile data communications capabilities. There are also wireless systems, such as Hughes DirecPC or the use of MMDS channels, that provide Internet access at fixed locations. My interest here is *mobile* access to the Internet — such as is provided by the Ricochet service.

that subscribership is growing at 34% per year.[8] Its new technology, Ricochet II, will also operate under Part 15 but will use the 2.4 GHz band as well as the 902-928 MHz band. The 2.4 GHz band has 83.5 MHz of spectrum available for such systems. Even though this spectrum has limitations associated with unlicensed operation, it is a substantial block of spectrum and, if used with a properly robust technology, could provide significant capacity. The largest investor in Metricom is Vulcan Ventures Inc., the venture capital firm operated by Microsoft cofounder Paul Allen.

Research on Improved Mobile Networking

14. Substantial resources are also going into improving future capabilities for wireless access to the Internet. For example, the Defense Advanced Projects Research Agency (DARPA) is conducting a major research initiative on wireless support of advanced data networking. This initiative, Global Mobile Information Systems or GloMo, aims to make the mobile environment comparable to other communications support structures in the defense information infrastructure — providing user friendly connectivity and access to services for wireless mobile users. This research aims to overcome limitations of range, latency, and data rate on radio channels; limitations in current network protocols that were designed around wired connections with their high data rates and low latency; and the incompatibility of networked applications with the characteristics of radio links. DARPA stated that their goal is to "enable utilization of MBone, World Wide Web, Video Servers, Video Conferencing, whiteboarding, electronic mail, and voice communications by mobile wireless users."[9] As part of GloMo, DARPA supports approximately 30 projects at firms and universities across the country. Participating institutions include MIT, Carniege-Mellon University, UC-Berkeley, Stanford, BBN, Rockwell, Rutgers, UCLA, and UC-Santa Cruz. To put this research in perspective, note

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8 See Metricom Press Release, "Metricom Strategy Validated by Microsoft/Qualcomm Wireless Data Announcement" (11 November 1998).

9 http://www.darpa.mil/ito/research/glomo/vision.html

that the current Internet grew from research supported by DARPA. The support of such research by DARPA demonstrates that one of the world's most respected sponsors of research in computing and communications believes it worthwhile to develop capabilities to support improved wireless access to the Internet. In addition, given the history of DARPA and of the organizations conducting the GloMo studies, it is reasonable to expect that valuable technologies for wireless networking will be developed and spun off to the civil economy.

15. The European Union sponsors similar research into wireless access to the Internet. Directorate-General XIII of the European Commission is sponsoring a multiyear, multination research project titled Advanced Communications Technologies & Services (ACTS).[10] That project, funded to the tune of about 700 million EUROs or about one billion dollars, includes several research tasks on wireless access to the Internet or to digital multimedia. These tasks include CRABS (Cellular Radio Access for Broadband Access), DOLMEN (Service Machine Development for an Open Long Term Mobile and Fixed Network Environment), MEMO (Multimedia Environment for Mobiles), MOMUSYS (Mobile Multimedia Systems), MULTIPORT (Multimedia Portable Digital Assistant), ONTHEMOVE (Multimedia Information Services), UMPTIDUMPTI (Using Mobile Personal Telecommunications Innovation for the Disabled in UMTS Pervasive Integration), and WAND (Wireless ATM Network Demonstrator). Although the task descriptions sometimes seem forced, no doubt in order to generate good acronyms, they clearly illustrate both a range of wireless multimedia projects and a clear commitment to the development of wireless Internet access and services. Just as DARPA funding has stimulated the development of key technologies in the United States, research support by the European Union has served to advance European industry.

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[10] DGXIII/B Ref: - AC1997/1339 15th May 1997.

16. Summing up, wireless can be used for Internet access today. However, such access is limited in capacity and coverage and does not appear to be widely used when compared with cellular mobile telephone service or wired access to the Internet. However, if one examines the record, one can identify substantial publicly funded research on wireless access to the Internet. It is highly likely that there are comparable levels of privately funded research that have not been disclosed. This research provides a clear sign that informed observers of the radio-communications and computer-networking world believe that there are large benefits to be gained from improving wireless Internet access. The research also provides a reasonable signal that technologies that are good complements to wireless networking, in particular improved networking protocols and terminal equipment, are likely to become available in the market.

Public Safety Uses of Data Networking

17. In mid-1995, the FCC and NTIA established the Public Safety Wireless Advisory Committee (PSWAC) made up of senior members of public safety agencies, such as FBI Chief Louis Freeh and New York City Police Commissioner Howard Safir, representatives of public safety organizations, as well as representatives from the major manufacturers. Among the tasks assigned to the PSWAC were identification of operational needs, spectrum requirements, and future technological options.

18. Responding quite quickly, given the constraints of the advisory committee process, in September 1996, PSWAC delivered to the FCC and NTIA a well-received final report. The following were among the primary conclusions of the PSWAC:

> The currently allocated Public Safety spectrum is insufficient to meet current voice and data needs, will not permit deployment of needed advanced data and video systems, does not provide adequate interoperability channels, and will not meet future needs under projected population growth and demographic changes.[11]

[11] "PSWAC Final Report" (September 1996) 19–20, para. 2.1.10.

> **Data communication needs are becoming as varied as voice needs, and are expected to grow rapidly in the next few years.** New services and technologies (*e.g.*, data systems enabling firefighters to obtain remote access to building plans and video systems for robotics-controlled bomb disposal) that are critical for Public Safety users to continue to fulfill their obligation to preserve life and property are now becoming available.[12] (emphasis added)
>
> **Wireless video needs are expected to expand in Public Safety applications.**[13] (emphasis added)

19. The PSWAC report also contains detailed appendices, prepared by the various subcommittees of the PSWAC. These appendices offer more detailed visions of the public safety community's future needs for nonvoice communications. Fire departments could benefit from the ability to transmit back video images of an incident to command headquarters as well as from the ability to transmit maps and diagrams to incident response teams. Emergency Medical Services (EMS) teams could use data communications capabilities for the transfer of patient records and the transfer of diagnostic data (e.g., 12-lead cardiogram results or ultrasound scans) to hospitals before the arrival of an ambulance. Space limitations prevent extensive quoting from these appendices, but I offer a few examples to give the reader a feeling of the beliefs of the experts who developed the PSWAC report. For more details, see Appendix A (Report of the Operational Requirements Subcommittee) to the PSWAC Final Report and Appendix B (Final Report of the Technology Subcommittee).[14]

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[12] Ibid., 20, para. 2.1.11.

[13] Ibid., 20, para. 2.1.12.

[14] I attended most of the PSWAC subcommittee meetings. I clearly recall a statement in one of those meetings by John Powell, former President of APCO, that he believed that many police officers would benefit from Internet connectivity today (1996) if it could be provided reliably, at reasonable cost, and without requiring excessive space in the patrol car.

20. The Operational Requirements Subcommittee identified the following requirements for wireless data communications in law enforcement:

> A need exists for real-time support of wireless mobile and portable computer systems capable of transmitting and receiving routine data queries and responses, electronic mail, location data and other graphics including fingerprints and mug shots, along with incident-specific data and intelligence. Based on the rapid market penetration of portable two-way radios into law enforcement patrol ranks in the 1970's, the International Association of Chiefs of Police Communications Committee has presented the possibility that over 75% of the nation's patrol force could be equipped with portable data terminals in the 2005-2010 time frame, given that affordable equipment and the required infrastructure become available.[15]
>
> Transmission of Reports. This system should accommodate transmission of forms and reports to central sites from mobile and remote locations. This capability will be used to transmit accident, arrest and incident reports, citation information and investigative reports to central locations in long data streams of up to several seconds. This capability will reduce paper transactions, increase officer field time, and speed transmission of vital information to command and administrative staff.[16]
>
> Many patrol cars used by law enforcement agencies now are equipped with mobile video cameras. . . .The ability to transmit full motion video from mobile video cameras directly to dispatch and other command and control installations is required on demand. Although constant transmission of this data from each individual officer or mobile unit is not required, the ability to monitor video from a unit is needed on an episodic basis in the event of officer assistance situations and other high risk events, or operations of high command interest.[17]
>
> Law enforcement requires the ability to transmit still photographs on demand to other locations. For example, an officer in the field

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15 "PSWAC Final Report," Appendix A: Operational Requirements Subcommittee Final Report, (September 1996) 16.

16 Ibid., 16.

17 Ibid., 17–18.

should be able to transmit a digital image of the violator in custody to a remote location upon demand.[18]

21. Another PSWAC subcommittee, the Spectrum Requirements Subcommittee, developed estimates of public safety spectrum requirements in the year 2010. Although any estimate that far into the future is, of course, uncertain, these estimates were developed with care to both the estimation of future technologies and the demand for service by public safety agencies. These forecasts indicate a substantially greater use of mobile radio capacity for data, wideband data, and video applications than for voice. The demand for nonvoice mobile communications capacity in 2010 was forecast to be three times the demand for voice communications capacity.[19]

The Land Mobile Communications Council

22. The Land Mobile Communications Council (LMCC) is an umbrella organization composed of many specialized organizations representing private land mobile users. In April 1998, the LMCC filed a petition for rulemaking with the FCC, requesting that the FCC allocate more radio spectrum for private land mobile use. Prominent among the reasons for this expanded allocation were the increased demand for radio channels that will be generated by future data and broadband demand. The LMCC identified a long list of future needs and stated that "any of these applications require access to broadband channels."[20] Appendix E to the LMCC petition for rulemaking contains specific estimates of future private land mobile spectrum requirements. The estimated spectrum requirements for data, wideband data, and video needs in 2010 exceed the estimated requirements for voice communications in 2010.

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[18] Ibid., 18.

[19] Ibid., 102. Voice and nonvoice capacity were measured in consistent units of megahertz based upon the technical assumptions on demand, source coding efficiency, channel modulation efficiency, and spectrum reuse.

[20] "LMCC Petition for Rulemaking" (April 22, 1998) 17.

Data Capabilities of Third-Generation Cellular

23. It has become conventional to refer to three generations of cellular mobile radio. The first generation consists of the analog systems deployed in the 1980s — systems such as Nordic Mobile Telephone (NMT), Advanced Mobile Phone Service (AMPS), and European Total Access Communications Service (ETACS). First-generation cellular systems had very limited data communications capabilities. The primary data communication mode was to attach a voice-line modem to the analog talking path and use it to carry data. This circuit-oriented approach was cumbersome, expensive, and unreliable. The second generation of cellular consists of the follow-on digital systems —most prominently GSM, North American TDMA (IS-54/136), and CDMA (IS-95). Second-generation systems delivered improvements in capacity and security and provided limited digital messaging and digital transmission capabilities as integral components of the service rather than as afterthoughts. For example, the GSM mobile service provided end user access to the underlying digital transmission capabilities and provided a digital Short Message Service (SMS) capable of transmitting about two lines of text (160 characters) to a user's terminal. The third generation of cellular will follow on these two earlier generations. Although, third-generation standards are still in the formal standards-development process at the time of this writing, the general form of third-generation standards appear to have been settled. The radio link will employ CDMA techniques operating with a chip rate three to four times faster than that used in the current IS-95 design. This higher rate will offer improved protection against multipath impairments. More important for the purposes of this discussion, third-generation cellular systems will also offer vastly superior data communications capabilities — supporting data rates up to two million bits per second and access to the radio channel on a packet-oriented as well as a circuit-oriented basis.[21] I am confident that these key features — high-speed data rates and support for packet-oriented

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[21] See, for example, the cdma2000 RTT Candidate Submission to US TG8/1, approved by TIA/TR45.5, 2 June 1998. This candidate submission meets the ITU requirements for IMT-2000 performance.

channel access — will be a part of any third-generation standard or deployment. Indeed, manufacturers such as Lucent, Qualcomm, and Ericsson are already bringing interim high-speed data capabilities to market.[22]

Observations on Future Demand for Nonvoice Wireless Communications

24. In the discussion above, I have considered several quite different indicators of the future demand for wireless access to the Internet and to other data networking, including (1) current product offerings by equipment manufacturers, (2) current service offerings by radio service providers, (3) the topics of government-funded research projects, (4) demand forecasts by experts in the public safety community, and (5) design specifications for third-generation wireless services. Each of these sources support the same message — wireless Internet access and wireless data networking delivers substantial value and will become increasingly important.

Implications of Expanded Use for CMRS Spectrum Needs

25. How many customers can be served by a CMRS carrier? The answer depends upon many factors — some technological, such as voice coding efficiency; some social, such as the ability to gain community permission to locate cell sites in residential neighborhoods; and some economic, such as how much traffic a consumer generates. Examining some rough bounds on such capacity provides insight into the constraining effects of the Commission's current spectrum cap for CMRS.

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[22] See http://www.qualcomm.com/cdma/infrastructure/oper/advport.html discussing IS-95b medium-speed (up to 115 kbps) capabilities to be supported by Qualcomm or the comments of Nitin J. Shah, wireless data networking vice president at Lucent who stated that Lucent gear will support data networking at rates up to 144 kbps by the end of 1998 (Lucent Press Release, 14 October 1998). At the time of this writing, Lucent is promising 144 kbps capability by mid-1999.

26. The technology I consider is one with the characteristics of the current CDMA system. I assume that an average CDMA channel (after allowance for soft-handoffs, etc.) can serve 30 active talking paths.[23] I do not consider queueing effects — consideration of queueing effects would reduce capacity slightly below the levels calculated here.[24] I assume that a CDMA channel requires 2.5 MHz of spectrum (1.25 MHz in each direction) and that sufficient cell sites have been acquired to permit operation with an average cell radius of one mile. This assumed cell size is rather small and boosts the calculated capacity.

27. Under these assumptions, a CMRS system with 10 MHz of spectrum serving traditional mobile telephone customers who tend to use their telephones lightly, say an average of 1.2 minutes in the peak hour (2% utilization), can serve 6,000 users in each cell or about 2,000 users per square mile.[25] Thus, one can expect that CMRS firms with 10 MHz licenses can be strong competitors in the mobile telephony market.

28. However, if we change our assumptions about traffic levels, as would be the case if CMRS were used as a substitute for wireline telephone service, then the number of subscribers that can be served falls markedly. If we also assume that data communications needs will exceed voice communications needs, as is frequently forecast for the wired world and as

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[23] This is slightly below the middle of the range of capacity estimates given by Goodman after adjusting for a 14,400 bps vocoder. See *Wireless Personal Communications Systems*, (Addison-Wesley, 1997) 225-226. It is however consistent with the field experience of system operators who find that CDMA delivers about six times the capacity of AMPS.

[24] The loss of efficiency from queueing effects decreases as the number of channels available at a cell site increases or if messages can tolerate delay (as is the case for email or web browsing). Queueing effects were quite significant for first-generation cellular systems but will be less significant for third-generation systems. Although including queueing effects would slightly strengthen the conclusions offered here, it would make the analysis harder to follow.

[25] The calculation is
(10 MHz/system $\div$ 2.5 MHz/channel) * 30 (conversations/channel) $\div$ (0.02 conversations/user) = 6,000 users. With the assumption of one-mile cells, this yields 6,000 $\div \pi$ = 1,910 users per square mile.

PSWAC did for the wireless world, the number of subscribers falls further. If we assume that the CMRS carrier has reached the 45 MHz cap, that it is trying to serve office and residential subscribers who generate an average of six minutes of traffic in the busy hour, and that data applications use four times as much capacity as does voice, then the carrier can serve about 1,100 subscribers from a single cell site or about 350 subscribers per square mile. But, this is far lower than urban population densities. The Census Bureau estimates that the population density in Washington, DC, is about 10,000 people per square mile and in the Los Angeles-Long Beach PMSA is about 2,200 people per square mile. Thus, under these assumptions there is a major mismatch between the capacity of the capped wireless system and the total market demand. If one assumed that larger cells were used, then the capacity would fall as the square of the increase in the cell radius. Similarly, if we assumed that it was most efficient to devote some of the channels in the CMRS system to continuing analog operations, the capacity would be reduced.

Additional Spectrum that Can Be Used for CMRS Services

29. If the Commission is concerned that CMRS firms will aggregate CMRS spectrum to restrict the supply of CMRS services and thereby raise the price of CMRS services it has a remedy — it can expand the supply of CMRS spectrum. Currently, about 185 MHz of spectrum is available for CMRS, as shown in Table 1.

Table 1. Existing CMRS Spectrum

Service/Band	Spectrum (MHz)
Cellular A	25
Cellular B	25
PCS A	30
PCS B	30
PCS C	30
PCS D	10
PCS E	10
PCS F	10
SMRS[26]	15
Total	**185**

30. The preferred spectrum for CMRS applications lies in the range 500 MHz to 3 GHz.[27] The constraints on the suitability of spectrum for CMRS use are not sharp. The constraints arise from both fundamental physics and the limitations of today's technology. The lower limit, 500 MHz, is set by antenna size and building penetration. As one proceeds down in frequency, the size of an efficient antenna becomes larger and radio waves become less able to penetrate buildings, tunnels, automobiles, and other closed objects. The upper limit is set by the increased blocking of radio signals at higher frequencies by trees and buildings and by the expense of building radio transmitters and receivers that operate at higher frequencies. There has been and continues to be research on mobile

[26] The exact number of MHz of spectrum used for SMRS varies from market to market depending upon how specific channels have been licensed and operated. I have chosen 15 MHz as a reasonable representative number.

[27] See, for example, the discussion in "White Paper: Frequency Band Selection Analysis," authored by Motorola attached as Appendix J to the PSWAC Spectrum Requirements Subcommittee Report.

communications at much higher frequencies such as 30 or 50 GHz.[28] Operation of terrestrial mobile communications at such high frequencies is not considered feasible today.

31. One possible source for more CMRS spectrum is the MMDS band. The MMDS service is allocated 186 MHz in the range 2.5 to 2.686 GHz. These frequencies were made available by the Commission for wireless cable. Wireless cable has failed to prosper operating on these channels. One large operator, CAI Wireless, had its Chapter 11 reorganization plan approved by the court in early fall.[29] Heartland Wireless Communications, a firm that claims to be the nation's largest wireless cable operator, announced on October 6, 1998, that it had reached an agreement with creditors to support a prenegotiated plan of reorganization and that it would file a bankruptcy petition under Chapter 11.[30]

32. Recently, the Commission has made more than five times more radio spectrum available for wireless-cable-type operations in the LMDS band than is available in the MMDS band. Thus, wireless cable providers using MMDS channels will face the threat of competition from LMDS as well as from DBS and cable systems. Converting the MMDS spectrum to CMRS operation would probably not be as difficult as was the case when the FCC made the 1850–1990 MHz range available for PCS. The FCC's proven record in keeping the microwave incumbents whole should simplify the transition if the Commission were to try to duplicate the approach it used in transforming a microwave band into the PCS band. Alternatively, the Commission could grant exchangeable, flexible licenses to the current MMDS operators and permit market evolution towards a more efficient arrangement. The

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28 See, for example, "Study of a 60-Ghz Cellular System," in *Mobile Cellular Telecommunications, Second Edition,* by William C. Y. Lee (McGraw-Hill, 1995) 639-641.

29 See "Court OKs CAI Bankruptcy Plan," *Multichannel News*, 5 October 1998.

30 Heartland Wireless Communications press release titled "Heartland Announces Agreement with Senior Bondholders to Support Plan of Reorganization," 6 October 1998, Dallas, TX.

Commission has already taken the first steps towards this approach by defining wide-area MMDS licenses, auctioning off the fill-in licenses, and permitting some technical flexibility.[31] The extensive holdings in this band by educational institutions that may have administrative difficulties in participating in market reallocation transactions may slow any otherwise-efficient transition to CMRS-like uses.

33. Another possible source for more CMRS spectrum is the block of spectrum now used for electronic news gathering. This spectrum, 105 MHz from 2.025 to 2.130 MHz, is formally allocated to the Broadcast Auxiliary Service (BAS) and is normally used in a point-to-point mode. Such point-to-point applications could be served at higher frequencies or, in some cases, using fiber.

34. The 36 MHz to be freed up for other than public safety applications from TV channels 60-69 furnishes a third possible source for more CMRS spectrum. This spectrum will not be available in major urban areas until digital television is widely adopted — an event that will not occur for many years.

35. A fourth source of additional spectrum for CMRS is provided by some of the spectrum being transferred to FCC control pursuant to the 1993 Budget Act (OBRA 93) and the 1997 Budget Act (BBA 97). These statutes required the federal government to turn over to the FCC significant blocks of spectrum. Some of those transfers have occurred, and others will take place in the future.[32] Some of that spectrum could be used for CMRS-like services.

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[31] See 47 CFR § 29.903(a) and Report and Order, MM Docket No. 94-131, (15 June 1995) para. 59.

[32] For a summary of the status of such transfers see "Spectrum Reallocation Report," by Edward Drocella, Jr., Steven K. Jones, and William T. Druhan, Jr., NTIA Special Publication 98-36 (U.S. Department of Commerce, February 1998).

36. A fifth source for additional spectrum is the band 1755-1850 MHz, which is currently used by the Department of Defense for satellite tracking, telemetry and control, point-to-point microwave, air-combat training systems, and some tactical systems.[33]

Table 2. Candidate Spectrum for CMRS-Like Services

Candidate	MHz
MMDS	186
ENG	105
TV Channels 60–69	36
OBRA 93, BBA 97	50
1755-1850	95
Total	**472**

37. To conclude, there is available substantial spectrum that can be redeployed to be used for CMRS or CMRS-like services. The spectrum identified in Table 2 is both technically suited for such applications and appears to be available, with relatively low costs for removing or working around incumbents. In addition, the unlicensed spectrum at 2.4 GHz and in the U-NII band is available to service providers. Any concern about output restrictions in the CMRS industry must take into account the potential capacity provided by such spectrum. Consumers would be better served if the FCC expanded the radio spectrum available for CMRS rather than restricting the operation of CMRS firms through artificial spectrum caps.

[33] See http://www.jsc.mil/images/speccht.jpg for a description of DOD uses of this band.

Conclusions

38. Every reasonable indicator predicts that the demand for CMRS services will increase beyond the levels originally forecast for voice alone. Substantial research is underway on mobile Internet connectivity. Cellular equipment manufacturers have promised to deliver order-of-magnitude increases in data communications capabilities and are working on even greater increases. Forecasts for the public safety sector and the private land mobile community indicate large growth in demand for data communications. However, the capacity of CMRS systems — even a CMRS system operating at the Commission's spectrum cap with the latest technology and small cells — is small compared with the total telecommunications demand in built-up areas. There is ample spectrum that could be used to provide CMRS services if the Commission believed that output restrictions were harming consumers. The Commission's CMRS spectrum cap does not reflect either the likely future demand for communications services or the availability of substantial additional spectrum that could be used to provide CMRS or CMRS-like services.

I declare under penalty of perjury that the foregoing is true and correct.

Charles L. Jackson January 22, 1999

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Dr. Jackson received a B.A. degree from Harvard College with honors in applied mathematics and M.S., E.E., and Ph.D. degrees in electrical engineering from the Massachusetts Institute of Technology. At MIT, he specialized in operations research, computer science, and communications. While a graduate student at MIT, he held the faculty rank of Instructor, taught graduate operations research courses, and was codeveloper of an undergraduate course in telecommunications.

Before becoming an independent consultant, Dr. Jackson was staff engineer for the Communications Subcommittee of the U.S. House of Representatives. At the Federal Communications Commission, he was special assistant to the Chief of the Common Carrier Bureau and engineering assistant to Commissioner Robinson. He has also worked as a digital designer and computer programmer. After leaving government, Dr. Jackson cofounded both the telecommunications consulting firm of Shooshan & Jackson Inc., whose practice was later combined with that of National Economic Research Associates, Inc., and Strategic Policy Research, Inc.

Dr. Jackson has served as an expert witness in litigation on cellular telephony, cable television, and other telecommunications and computer issues and has testified before several state utility commissions.

He has authored or coauthored numerous studies on public policy issues in telecommunications and has testified before Congress on technology and telecommunications policy. Over the last several years, he has also directed or participated in projects on acquisition analysis, market planning, and product pricing. He has written for professional journals and the general press, with articles appearing in publications ranging from *The IEEE Transactions on Computers* to *Scientific American* to *The St. Petersburg Times*. He holds a U.S. patent on an alarm signaling system.

Dr. Jackson is a member of the IEEE, the Internet Society, the American Mathematical Society, and Sigma Xi. He is an adjunct professor of electrical engineering and computer science at George Washington University, where he teaches a graduate course in mobile communications. From 1982 to 1988, he was an adjunct professor at Duke University.

EDUCATION

Massachusetts Institute of Technology
Ph.D., Communications and Operations Research, 1977
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EMPLOYMENT

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Strategic Policy Research, Inc. (SPR), Bethesda, MD
1992–1997 **Principal.** Provided telecommunications and public policy consulting services for a variety of clients in the telecommunications industry.

National Economic Research Associates, Inc. (NERA), Washington, DC
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Communications Subcommittee, U.S. House of Representatives, Washington, DC
1977–1980 **Staff Engineer**. Was responsible for common carrier legislation and spectrum-related issues.

Common Carrier Bureau, Federal Communications Commission, Washington, DC
1976–1977 **Special Assistant to Chief**. Was responsible for technological issues and land mobile policy.

Federal Communications Commission, Washington, DC
1975–1976 **Engineering Assistant to Commissioner Robinson.**

CNR, INC., Boston, MA
1973–1976 **Consultant.** Worked on the implementation of digital communication systems over dispersive channels.

Massachusetts Institute of Technology, Cambridge, MA
1973–1976 **Instructor.**
1971–1973 **Research and Teaching Assistant.**

Signatron, Lexington, MA
1968–1971 **Research Engineer.**

Stanford Research Institute, Menlo Park, CA
1966–1968 **Programmer.**

PROFESSIONAL ACTIVITIES

Member, Sigma XI, Institute of Electrical and Electronics Engineers (IEEE), IEEE Computer Society, IEEE Communications Society, IEEE Information Theory Society, American Association for the Advancement of Science, the Internet Society, and the American Mathematical Society.

From 1987–88, served on the Board of Directors of the Telecommunications Policy and Research Conference. Chairman of the Board, 1988.

Chairman, IS/WP1 (Policy and Regulation) of the FCC's Advisory Committee on Advanced Television.

Executive Committee Member, University of Florida's Public Utility Research Center (PURC).

Member, U.S. Department of Commerce Spectrum Planning and Policy Advisory Committee.

TESTIMONIES

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